THE
JOURNAL
OF
Nervous and Mental Disease.

Vol. VI. JANUARY, 1879. No. 1.

Original Articles, Selections and Translations.

ART. I.—ON THE STRUCTURE AND FUNCTION OF THE GANGLIONIC BODIES OF THE CEREBRO-SPINAL AXIS.

BY DR. H. D. SCHMIDT,
PATHOLOGIST OF THE CHARITY HOSPITAL, NEW ORLEANS,
AND MEMBER OF THE AMERICAN NEUROLOGICAL
ASSOCIATION.

IN my paper on the "Structure of the Double-Bordered Nerve Fibre," published in the *Monthly Microscopical Journal* of London, May, 1874, I briefly alluded to the structure of the ganglionic bodies of the cerebro spinal axis, showing that it is similar to the structure of the axis cylinders of nerve fibres. Shortly after, in a communication to the Royal Microscopical Society, published in the July number of the same journal, and embracing, in the form of a synopsis, the principal facts, which I had elicited from a series of microscopical researches upon the structure of some of the nervous tissues, I again made some limited remarks upon the structure of these bodies, postponing the details to some more convenient time.

Since that time I have had ample opportunity of studying the subject still closer, and am now prepared to present he results of these studies to the profession, and in a more perfect and definite form.

To form a correct idea of the structure of the different nervous tissues, we must bear in mind that the whole nervous apparatus consists, in its central as well as in its peripheral parts, of only three essentially nervous anatomical elements. These are fibrils, nuclei, and granules, and, moreover, a certain intermediate so-called " inter-cellular" substance, by means of which granules, lineally arranged in rows, are united to each other and transformed into fibrils. The only difference existing between the individual nervous tissues consists in the morphological arrangement and mutual relations of these elements. The nerve-medulla and tubular membrane of the dark-bordered nerve fibres, though they may serve some special purpose, must be regarded as non-essential to the liberation and propagation of nervous energy.

In the cerebro-spinal axis, these ultimate anatomical nervous elements are supported and held in their mutual positions by an exceedingly delicate fibrillous connective tissue, the neuroglia, characterized by remaining unaffected by acetic acid. The axis cylinders of the peripheral nerve fibres and their peripheral terminal organs, together with the various ganglionic bodies of the nerve centres, are composed of one or more of these anatomical essential nervous elements.

The discussion of the structure of the ganglionic bodies, or ganglion cells of the cerebro-spinal axis, requires a few preliminary remarks relating to that of the axis cylinders of the dark-bordered nerve fibres, which, as we know, are but the direct continuations of the subordinate branches of the processes of the ganglionic bodies. All axis cylinders, whether surrounded by covering layers, as in the dark-bordered nerve-fibres, or whether appearing uncovered, as they are met with in the sympathetic nerves, consist of a number of individual nervous fibrils which, united by a homogeneous inter-fibrillous substance, are surrounded by a delicate, tubular sheath. Both the sheath and the inter-fibrillous substance appear to be continuous with each other, and are very probably of the same nature as the intermediate substance, by the agency of which the original rows of granules were transformed into fibrils during the earlier stages of the development of the axis cylinders in the embryo. As regards the individual fibrils of the axis cylinders, I repeat my former assertions in stating that they are not *smooth* fibrils held together by a granulous inter-fibrillous substance, as they were first described by Max Schultze, and as they are, perhaps, still looked upon by the majority of histologists; but that, on the contrary, they present a knotted appearance, and are held together by a homogeneous inter-fibrillous substance. The knotted appearance of these fibrils, indicating their *original anatomical composition of elementary granules*, can be recognized on all axis cylinders, whether large or small, fresh or hardened by reagents. For further details concerning the structure of the axis cylinder, I must refer to my paper on the "Dark-Bordered Nerve Fibre," already mentioned above, and also to my researches upon the "Development of the Nervous Tissues in the Human Embryo," published in the JOURNAL OF NERVOUS AND MENTAL DISEASE, July, 1877.

In passing from the axis cylinders toward the centre we, of course, arrive at the processes of the ganglionic bodies, and, as the axis cylinders represent nothing else but the subordinate branches of the processes, it becomes obvious that the latter are composed of the former, and that both are very probably also identical in structure. And this is really the case as far as their structural elements are concerned. In the mutual relation of these elements, however, a slight difference is already observed, which, bearing upon the propagation of nervous stimuli, deserves our attention. It consists in the individual fibrils not being applied to each other as closely in the processes as in the axis cylinders. In the processes, therefore, the individuality and the granulous character of the fibrils, indicated by the longitudinal and transverse striæ or furrows, becomes more apparent with the increase of the process in thickness, and the nearer to its origin from the body of the ganglionic cell. The component granules of the individual fibrillæ also, are rendered more distinct and prominent by a decrease of the intermediate substance which binds them together. Finally, upon the ganglionic body itself, the individuality of the granules, of which the fibrils are originally composed, is most distinct, so that the whole ganglionic body may appear to the careless observer as a mass of granular protoplasm—such as it was generally considered not many years ago.

While, however, upon the ganglionic body, the granules are seen more distinctly than upon the processes, the longitudinal furrows or inter-fibrillar spaces have not proportionately increased in width ; and it is owing to this circumstance that the individual fibrillæ cannot always be traced very distinctly while passing over the body from one process into the other. This is particularly the case on those large ganglionic bodies of the anterior horns, which, on account of their bulk, do not transmit sufficient light through their centres as required for the examination. Nevertheless, even in these large specimens, the individual fibrillæ can almost always be distinguished and traced, as they spread over a considerable portion of the body. The course of these fibrillæ is most advantageously studied in those large, spindle-shaped ganglionic cells, met with in the anterior horns from which only a few processes are seen to arise (Fig. 1). The individual fibrillæ of the processes and of the ganglionic body itself, as well as their granular composition, can be distinctly recognized under all conditions, whether the specimen be fresh and uncolored, or slightly hardened and colored. The best method, however, is that proposed by Gerlach, by which beautiful preparations may be obtained. In examining one of these ganglionic bodies of the anterior horns, prepared and isolated by Gerlach's method, as represented in Fig. 1, we should first direct our attention to the fibrillæ of one of the processes, and, after having them distinctly recognized and studied, follow them as they pass upon the surface of the ganglionic body. This can be easily accomplished in adapting, by a careful management of the fine adjustment of the microscope, the focus successively to every point of the fibrillæ, spreading themselves over the body of the ganglionic cell. In tracing then the fibrillæ of a neighboring process in the same manner over the latter, it will be found that they cross in more or less acute angles those of the first process.

In some instances the decussation of the fibrillæ of the two processes can be seen almost without altering the focus. If not, the slightest alteration of the latter will bring it into view. The fibrillæ of one process do not enter the body of the ganglionic cell in the form of a bundle, but diverge from each other, either in the form of a hollow cone, to be distributed while embracing the nucleus over the whole body, or radiating over a portion of the body only.

The distribution of the fibrillæ over the ganglionic body is most distinctly seen on those smaller, strictly spindle-shaped, ganglionic cells with only two processes, representing the opposite poles of the body. Here it will be observed that they diverge in the form of a hollow cone, around the nucleus; and, after having embraced this body, gradually approach each other again to form the opposite process. For a long time I have been in doubt whether the fibrillæ of the processes would be sufficiently large in number to surround the nucleus completely, or whether they were giving rise to additional branches to fill up the interspaces left. From numerous close examinations, however, I am now convinced that the nucleus is only embraced by the fibrillæ of the processes. In the smaller spindle-shaped ganglionic bodies, as mentioned before, the fibrillæ of one process may be traced, in many instances, directly into the other process. Not all the fibrillæ arriving at the ganglionic body through one process, pass over the ganglionic body to enter the processes arising on the opposite side; on the contrary, a smaller or larger portion may enter a neighboring process, and without ever having passed the nucleus, direct their course toward the periphery. This fact can be demonstrated without difficulty. In examining the fibrillæ directly around the nucleus, especially in the larger ganglionic bodies, they present the appearance of being concentrically arranged around this body, from which the conclusion might be drawn that the fibrillæ representing the axes of the processes encircle, to some extent, the nucleus, before they leave the ganglionic cell through one or the other process. As all fibrillæ which can be traced over the surface of these larger bodies, are probably derived from the periphery or surface of the processes, it is difficult to determine the exact course of those representing the axis of the processes. These may either, in preserving their individual fibrillar character, pass only over a portion of the nucleus, and then leave by way of another process; or it may be that in the vicinity of the nucleus, the mutual connection of their component granules becomes looser, the whole assuming the appearance of a granular mass. If this were the case, however, it would necessitate a difference in function between the axial and peripheral fibrillæ of a process. Therefore, it is more plausible to presume that the arrangement of the axial fibrillæ around the nucleus is the same as, or, at least, similar to that of those derived from the surface of the process. Several years ago I met with the remaining portion of a ganglionic body, which had been divided by the knife in the making of a section. As the section had passed close to the nucleus, several unbroken fibrillæ could be seen passing directly in front of this body, while fragments of others, resulting from the section, were observed in the vicinity. Fig. 3 represents the specimen. This observation alone would show that the fibrillæ simply pass over the nucleus without encircling it.

From the above demonstrations the conclusion may then be drawn, that the ganglionic body or cell is formed, in accordance to its size and form, by a smaller or larger number of nervous fibrillæ—mostly derived from the axis cylinders of the nerve fibres—embracing an independent body of a spherical or ovoid form, known as the nucleus. In embracing the nucleus, the fibrillæ of the different processes not only decussate, but probably also interlace with each other, particularly those in its immediate vicinity. While surrounding the nucleus, the fibrillæ form no direct communication with it, but remain isolated. The interspaces left between the fibrillæ of the ganglionic body are filled up by the same inter-fibrillous substance which connects the fibrillæ of the processes, or of the axis cylinders.

The nucleus of the ganglionic body differs from the *nuclei* of other tissues, in the complexity of its construction. It represents a vesicle filled up by a granular protoplasm containing in its centre a smaller vesicle, the so-called nucleolus. The vesicular nature of both the nucleus and nucleolus is indicated by the double contour which they present. The complexity of construction just mentioned, will be found in the nucleolus. This body, namely, wherever it is met with in the nuclei of other normal cells or tissues, is always homogeneous in its nature, representing a large granule, bordered by a single contour. In the nucleus of the ganglionic body, however, it appears in the form of a vesicle, distinguished by a fine and distinct double contour, and containing two minute bodies which are characterized by their reddish lustre; the remaining space is filled up by minute granules. The one of these minute bodies appears in the form of a vesicle of about $\frac{1}{600}$ mm. in diameter; it is also bordered by a double contour, and, containing a dark granule in its centre, is especially distinguished by its bright and reddish lustre. The other minute body is somewhat smaller, and sometimes absent. Very frequently several nucleoli are found in the nuclei of the larger ganglionic bodies; these, however, contain no vesicles, but are only filled up with minute granules. The form of the nucleus seems to be in accordance with the particular form of the ganglionic body, which, in its turn, is determined by the number of the processes, and by the direction in which they approach the nucleus. Thus, in those large, more or less round, ganglionic cells, the nucleus also presents a round form; while in others of an oblong shape, the nucleus assumes an oval or oblong form. In the larger ganglionic bodies of the cortical layer of the cerebrum, being somewhat pyramidal in shape, the nucleus, though mostly oval, nevertheless presents in many cases also a pyramidal form. It seems, therefore, that the form of the nucleus is to a certain extent determined by the course of the fibrillæ embracing it.

All ganglionic bodies of the cerebro-spinal axis are constructed in the manner described above. Even in the smaller kind, met with in the upper strata of the cortical layer of the brain, the individual fibrillæ of their processes may be distinguished. In many ganglionic bodies the course of the fibrillæ over the body is hidden by the accumulation of pigment granules, usually found near the origin of the largest process; but, even in these instances, it may be detected upon that portion of the body which is free from granules.

The larger ganglionic bodies are invested by a delicate sheath, extending over the processes, and being, moreover, continuous with the sheath of the axis cylinders. Upon the body of the ganglionic cell, the sheath is not easily demonstrated, for the reason, as I suppose, that it is closely united, or even fused with the inter-fibrillous substance; but upon the processes it can be seen; in many instances it manifests, upon the larger processes, its presence by a number of minute spindle-shaped nuclei, which it contains.

Before dismissing the ganglionic bodies of the cerebro-spinal axis, I shall have to make a few remarks upon the probable destination of the subordinate branches arising from the division of the processes, to which I have already alluded, on another occasion, some years ago. Since the discovery of the so-called axis cylinder process by Deiters, the idea has been prevailing that this process, without undergoing any division, represented an axis cylinder from the beginning, which, not far from its origin, would be surrounded by a nerve medulla and a tubular membrane, and thus transformed into a dark-bordered fibre, was to leave the grey matter of the spinal marrow, and join the anterior roots of the spinal nerves. All nerve fibres, forming these roots of the spinal nerves, therefore, would receive their axis cylinders from this source. It is true, that from a number of the larger ganglionic bodies, one or two processes, with a diameter about equal to that of the axis cylinder of a large, double contour nerve fibre, are observed to arise; but whether the axis cylinders of all the fibres of the spinal nerves are derived from this source only, is by no means an established fact. As far as my own experience goes, I must confess, that in the numerous preparations which I have made and examined, I have never been so fortunate as to behold the transformation of this axis cylinder process into a double contour nerve fibre, as close to its origin as I have seen it represented on the paper. I always found the process torn. Nevertheless, I would not contest the possibility of such an occurrence. Whether the axis cylinders of all large nerve fibres are derived from this source, is a question which must be negatively answered, as I have, in several instances, observed large axis cylinders arising from the larger processes, and have traced them to a considerable distance. In one instance, I observed three axis cylinders from $\frac{1}{300}$ to $\frac{1}{200}$ mm. in diameter, arising from one of the larger processes, one of which attained a length of more than $\frac{1}{5}$ mm. before it was torn. As regards the smaller axis cylinders, I have observed some of $\frac{1}{400}$ mm. in attaining a length of nearly one millimetre; and others of only $\frac{1}{600}$ mm. diameter, attaining a length of from $\frac{1}{4}$ to $\frac{1}{2}$ mm. Those naked axis cylinders which are met with in every fragment of grey matter of the anterior horns, when prepared by a weak solution of chromic acid, or of its salts, and carefully dissected by means of fine needles, are undoubtedly identical with those arising from the divisions and subdivisions of the larger and smaller processes of the ganglionic body; and if in reality—with the exception of the so-called axis cylinder processes—none of them, after their transformation into a double contour nerve fibre, contributes to the formation of the anterior spinal roots, it is more than probable that the majority enter the anterior and lateral white columns. From the examinations which I have thus far made in regard to the particular direction of the various processes of the ganglionic bodies of the anterior horns, on thin, very transparent, transverse and longitudinal sections of spinal marrow, it seems that the individual processes do not point in a particular direction. Accordingly, I have seen the largest process, which cannot be easily mistaken, pointing in one instance, in the one, and in another instance, in the other direction. The same I have found with the axis cylinder process. As the axis cylinders arising from the processes do not pursue a straight course, but, on the contrary, describe greater or smaller curves, before leaving the grey matter, it becomes almost impossible to determine their destination by the direction in which their parent process points.

As regards the termination of the finest subdivisions of the processes in the grey matter itself, I have spared neither trouble nor pains to come to some definite conclusion. Some years ago, in my first communication to the American Neurological Association upon the structure of the nervous tissues, I stated in regard to this subject that I had never been able to discover the existence of a minute nervous net-work in the grey matter of the spinal marrow in which the finest subdivisions of the processes were supposed to terminate, and from which, moreover, nerve fibres were to arise, such as described by Gerlach. At the same time, I also stated that from a physiological point of view I had presumed the existence of this net-work; and as my examinations had been made on specimens hardened in a chromic acid solution and uncolored, I promised to repeat these examinations on specimens prepared by Gerlach's own method, at a future day. As besides Gerlach, other histologists have professed to have seen this net-work, and, as furthermore, its existence or non-existence has some important bearing upon the particular mode in which the spinal marrow operates, I shall not hesitate to give a minute account of the examinations which I have since made.

In the latter part of August, 1877, after having made the preliminary arrangements with a butcher in this city, I drove to his yard in the evening, near sundown, when he was ready to kill his calves, carrying with me not only a solution of bichromate of ammonia, strictly prepared after Gerlach's formula, but also a similar solution of bichromate of potassa. The calf was killed and the spinal marrow removed without injury by the butcher, with the help of his sharp hatching knife, as neatly as and more rapidly than I could do it myself. I quickly removed the pia mater from the cervical enlargement of the still warm cord, and with my section knife, almost sharper than a razor, made a number of longitudinal sections of the anterior horns, which were immediately put in the above-mentioned solutions. On my returning home soon after they were put in a cool place, where they remained for two days; after which time they were transferred to the solution of carmine. Twenty-four hours after this time I commenced my examinations, which, in order to observe the gradual changes which might be caused by the ammoniacal solution of carmine upon the tissues, were repeated during five days. These examinations throughout were made in the most exact and careful manner. I am accustomed to work with needles, the points of which, about four millimetres in length, are very slender and bent at an angle of 45°. The very point, which I finish myself upon a hone, is examined during this process with a strong loupe, and I do not consider it in order until it takes a hold upon the skin of the finger with the slightest touch. It is of great importance in these minute dissections that the very point of the needle should be as slender and sharp as it can possibly be made, in order to penetrate between the delicate elements of the nervous tissue, which by the pressure of a dull point would be torn and destroyed. In dissecting the nervous matter with the view of isolating the ganglionic bodies with their processes, the tissues should, by the most delicate manipulation of the points of the needles, be loosened, avoiding at the same time all tearing, and also too great a pressure of the points upon the glass slide. As I always observe these rules in my labors, I obtained from the tissues prepared by Gerlach's method some of the most beautiful preparations of isolated ganglionic bodies I have ever made. Fig. 2 is a true copy of one of these bodies. As will be observed in this drawing, some of the processes have been torn at a certain distance from their origin, while others have been successfully separated from the surrounding nervous elements, without injury, down to their finest ramifications. As regards their coloring, it is worthy ot note that it becomes fainter with the decrease of the diameter of the ramifications. Thus, while the nucleus is colored most intensely, and the ganglionic body with its larger processes presents the brilliant color of the carmine, the subordinate branches become fainter in color in proportion to their decrease in diameter, until the finest ramifications appear only colored pink. This difference in color, however, is only apparent, and is not owing to a greater power of absorption which the larger processes possess in preference to the smaller. On the contrary, it only depends on the mass of the fibrillæ. The greater the mass of the fibrillæ the more, with the exception of the red ray, are they able to absorb the other rays of light. Thus, in cases where a portion of the sheath of a process has been torn away, and the individual fibrillæ, of which the process is composed, separated, as is seen in Fig. 4, it will be found that while the uninjured portion of the process presents the perfect color of the carmine, the isolated fibrillæ appear only pink.

Besides these finest ramifications still in union with their parent processes, a number of others were met with in every preparation made; but, as regards the fine net-work in which they are said to terminate, no trace of it could be found. The same results I found in examining new preparations which I successively made for five days. The only difference observed was a deeper coloring of the whole mass, owing to the extension of the coloring matter into the interstices of the granular substance and the neuroglia. The results, therefore, which I obtained from these examinations made on specimens of grey matter of the spinal marrow, conscientiously prepared after Gerlach's own formula, were the same as I obtained from my examinations of uncolored chromic acid preparations a number of years ago. And as the preparations under discussion were made with the greatest care and accuracy, and examined with superior objectives, made by Mr. Tolles, I feel conscientiously bound to deny the existence of a fine nervous network in the grey matter of the spinal marrow, such as Gerlach has described, in which the finest ramifications of the processes of the ganglionic bodies terminate, and from which nerve fibres arise.

Nevertheless, there exists a net-work in the grey matter of the spinal marrow, but only in appearance. It is that representing the delicate connective tissue, pervading throughout the substance of the cerebro-spinal axis, the neuroglia; it is the same apparent net-work which has repeatedly deceived me when I was searching for a true nervous net-work. The very fine fibrillæ of the neuroglia, decussating with each other, present, indeed, the appearance of a delicate net-work with rhomboidal or irregularly shaped meshes when examined in a section or fragment of grey matter. This apparent net-work, however, becomes unraveled as soon as the fragment is carefully dissected into its component anatomical elements, as above described. The fibrillæ of the neuroglia will then appear of a quite considerable length, showing that they never formed part of a net-work of fine regular meshes. The appearance of the neuroglia in the form of a net-work with meshes of a rhomboidal or otherwise irregular form, caused by the decussation of its fibrillæ, is sometimes very striking, and may deceive. I would, therefore, not entirely deny its reticular character, as it is possible that it really represents a delicate net-work of fine elastic tissue fibrils with large meshes. That the neuroglia belongs to this class of connective tissue, is rendered more probable by its immunity from the action of acetic acid. As Gerlach's drawing of his net-work in Stricker's *Handbuch der Gewebelehre*, etc., resembles in some measure the apparent net-work of the neuroglia, I am inclined to think that he mistook the latter for the former, an error which I was very near committing myself, as stated before. The fine fibrillæ of the neuroglia may be easily distinguished by their remaining uncolored. They present a colored appearance only when entangled in the granular substance, but whenever they are examined isolated they at once appear uncolored, for they do not absorb the coloring matter.

If, then, the ultimate ramifications of the processes in question do not terminate in a fine nervous net-work, the question remains to be answered—in what manner do they terminate, and, at the same time, establish a communication between the ganglionic bodies in the grey matter? I have suggested once before that most probably a communication may exist in the form of anastomoses, or, in other words, of a net-work of large and irregular meshes. Though I cannot adduce sufficient evidence to support this suggestion, I have, nevertheless, met with fragments of anastomosing fibrillæ in a few instances, such as are represented in Fig. 5. The fibrillæ forming the anastomosis were exceedingly fine, about from $\frac{1}{700}$ to $\frac{1}{800}$ mm. in diameter; they appear uncolored, and a number of fine granules were observed to adhere to them. There is no doubt but that they represented either portions of the neuroglia or portions of anastomosing nervous fibrillæ. To which order of fibrillæ they really did belong, farther investigations will decide.

In the foregoing pages I have endeavored to show that the ganglionic bodies consist of a number of fibrillæ embracing a nucleus; in other words, that they represent a plexus formed by a greater or smaller number of fine, granular, nervous fibrillæ around a pre-existing nucleus of a complex nature. As there exists no direct connection between the fibrillæ and the nucleus, they represent two distinct anatomical and, probably also, physiological elements of the ganglionic body. And this seems to be the rule throughout the whole nervous apparatus without regard to the mutual arrangement of the fibrillæ themselves; that is, whether they simply pass over the nucleus while lying parallel to each other, or whether they embrace this body in the form of a plexus, or even whether they surround it in the form of a net-work. In all cases we meet with fibrillæ surrounding a nucleus, and in order to show that this is a rule in the construction of ganglionic bodies, I shall now describe the manner in which these bodies are formed in the cerebro-spinal axis of a certain animal belonging to the lower orders of vertebrata, and already known for the enormous size of its colored blood corpuscles and other peculiarities in its organism. I refer to the *Amphiuma tridactylum*, vulgarly called "congo eel" or "congo snake" by the people of New Orleans and vicinity. Several years ago, in a foot-note to my paper "On the Construction of the Dark-Bordered Nerve Fibre," I very briefly alluded to the construction of the ganglionic bodies of the spinal marrow of this animal, stating that they consisted only of a large nucleus over which a few single fibrillæ passed to form a process or axis cylinder. The examinations upon which this statement was based, had been made only in a superficial manner after the paper was already written, and on specimens of spinal marrow which had been lying in a solution of chromic acid for some time. Since that time I have examined the subject more thoroughly, and have been surprised by the simplicity of construction of the ganglionic elements in this animal. I shall begin with those of the spinal marrow.

In the Amphiuma tridactylum, the ganglionic bodies of the spinal marrow consist of large nuclei, surrounded by a network of short granular fibrillæ. These nuclei appear to consist of a dense protoplasm, of considerable refractive power, which in most instances interferes with the examination of the nucleolus within. In the fresh nucleus, therefore, the nucleolus is not often seen, unless by the action of acetic acid. The nucleus (Fig. 6, *a*) presents a homogeneous, slightly greenish appearance, and is bordered by a clear double contour. The nucleolus also shows a double contour, and one or two small granules within its centre; its diameter measures about $\frac{1}{150}$ mm. The net-work closely surrounds the nucleus, and its meshes, together with the granular nature of its component fibrillæ, can be distinctly recognized in the fresh specimen. From the net-work a few fibrillæ are seen to arise, which, by converging toward each other, form a small axis cylinder process (Fig. 6, *b*). Some other fibrillæ, also, arising from the net-work, pass to neighboring ganglionic bodies (Figs. 7 and 9).

The form and size of the ganglionic bodies, as may be inferred from the description of the construction just given, depend upon the form and size of the nucleus, which differs very much in different parts of the spinal marrow. In examining a transverse section of the spinal marrow of the amphiuma, it will be found that the distribution of its ganglionic bodies deviates to a certain extent from that usually observed in the higher vertebrata. While in the grey matter of the spinal marrow of mammalia, the ganglionic bodies, especially those of the anterior horns, are mostly arranged in groups, and confined to the grey matter, they form, in the amphiuma, not only the greater part of the whole grey matter, but are found singly distributed throughout the white columns. In the grey matter, they are crowded around the central canal (Fig. 13), forming a ganglionic zone of considerable breadth, from which they extend to form the anterior and posterior horns. The ganglionic zone or ring around the central canal is particularly formed by the smaller bodies, of a more or less roundish form (Fig. 9), measuring from $\frac{1}{50}$ to $\frac{1}{30}$ mm. diameter. Extending from this zone into the anterior and posterior horns, the ganglionic bodies increasing in size, assume a more oblong form, and are placed in such a manner that their long axis is more or less parallel with the radius of the section of spinal marrow. Thus, the largest ganglionic bodies (Fig. 13) are found at the periphery of the grey matter, extending into the white columns. This arrangement, however, is only a general one, for there are many exceptions met with, in which smaller ganglionic bodies are placed near the periphery, or, also, in the white columns. The long diameter of the oblong ganglionic bodies ranges from $\frac{1}{40}$ to $\frac{1}{20}$ mm.

The ganglionic bodies forming the zone around the central canal, are mostly of the smaller kind. They are placed close to each other, and, as it appears, communicate by means of the fibrillar network surrounding the nuclei. From the network of a number of these bodies, a process consisting of only one fibril is seen to arise. Whether this process passes at once to the periphery of the grey matter, to contribute to the direct formation of axis cylinders, I cannot say; but it is certain that filaments arising from the net-work of the individual ganglionic bodies anastomose with each other, as seen in Fig. 9; and, also, that from these anastomoses, independent nervous fibrillæ arise, which, during their course to the periphery, join, in order to form axis cylinders. From the net-work of the larger ganglionic bodies, distinct processes, consisting of two or three fibrillæ, are seen to arise (Figs. 10 and 11). These processes, the course of which I have been able to trace to a considerable distance, and in a direct line toward the white columns, represent distinct axis cylinders. From the largest ganglionic bodies, met with at the periphery of the grey matter, especially in the anterior horns, processes of considerable size are seen to arise. The fibrillæ of these processes, however, are not all derived from the net-work of the body from which the process apparently arises; but, on the contrary, the process is formed by additional processes, or axis cylinders, coming from other parts, and surrounding the ganglionic body in question, before joining its process, as seen in Fig. 11. In these instances, the fibrillæ appear to be imbedded into an inter-fibrillous substance, which connects even a number of these larger bodies into one general mass. Considerable portions of this inter-fibrillous substance are frequently found adhering to the larger ganglionic bodies.

The delicate net-work surrounding the nuclei consists, as already stated, of very fine fibrillæ. In the fresh specimens, especially, the individual granules, of which these fibrillæ are originally formed, can be distinctly seen. The meshes formed by these short and granular fibrillæ are of an irregular polygonal form. In accordance with the form of the nucleus, which they surround, they appear either more round or oblong. In many instances, small, dark looking granules are observed at the angles of the meshes. Besides the communication formed between the net-works of neighboring ganglionic bodies by those anastomosing filaments already described (Fig. 9), the neighboring net-works seem to be furthermore connected by their meshes. Thus, in dissected preparations, a number of ganglionic bodies are met with, upon which the net-work does not pass to the very margin, because here it has been torn from the net-work of the neighboring ganglionic body by the manipulation with the needles. In chromic acid preparations, this phenomenon is especially observed, on account of the remaining portion of the net-work contracting by the action of the acid. For this reason, the specimen should not have remained too long in such a solution. The best preparations are obtained by putting the spinal marrow, directly after its removal from the animal, into a very weak solution of bichromate of potassa, in which it is left for twenty-four, or even forty-eight hours, and then transferred to the carmine solution. Being prepared in this manner, small portions of grey matter, distinguished by a more intense coloring, are dissected by means of fine needles. If the preparation remains longer in the solution, the net-work becomes too hard, causing the breaking of the communicating fibrillæ. I have succeeded in making thin sections of spinal marrow sufficiently hardened for the purpose, which, after being colored, were mounted in a solution of gum dammar. The highly refractive power of the colored nuclei, however, interfering with the rays of light proceeding from the net-work, deprives these preparations of their usefulness. For this reason, glycerine has proved to be the best medium for the study of the more intimate relations of the nervous elements concerned.

The arrangement of the nervous elements in the cerebrum of the Amphiuma is still more striking than the one in the spinal marrow just described. The whole nervous substance here seems to consist of a continuous net-work, with small regularly formed meshes in which the nuclei are literally imbedded. From the delicate meshes of this net-work, especially in the vicinity of the nuclei, larger meshes, consisting of coarser fibrillæ, are arising to give origin to those fibrillæ forming the axis cylinders of the nerve fibres (Fig. 14). The nuclei are in every respect of the same nature as those in the spinal marrow, already described, with the exception of their form, which is more or less round. In thin transverse vertical sections of the cerebrum, large accumulations of nuclei are observed to form the surface of the ventricles. They appear to represent the larger cerebral ganglia, the corpora striata, thalami optici, etc., and it is especially in the vicinity of these masses that the greater portion of axis cylinder fibrillæ are seen to arise. Properly speaking, there is no distinct ganglionic cortical layer of the cerebrum, for the nuclei representing this layer are comparatively few in number, and singly scattered throughout the general net-work, without any apparent system or order.

The arrangement of the nervous anatomical elements in the cerebro-spinal axis of the Amphiuma, being more simple in form than in animals of a higher order, shows again most distinctly the individuality of the fibrillar or conducting element, opposite the nuclei. Before drawing any general conclusions, however, from the facts presented, we will take a glance at the structure of the ganglionic bodies met with in the ganglia of a still inferior order of animals, namely, the insects.

The ganglionic bodies found in the ganglia, representing the nervous centres of insects (Figs. 15 and 16), apparently consist of a mass of granular protoplasm, inclosing a large clear nucleus of about $\frac{2}{75}$ mm. in diameter. This nucleus, the vesicular nature of which is indicated by a fine double contour, contains a nucleolus of about $\frac{1}{200}$ mm. in diameter, which, however, is composed of three large granules of a greenish lustre, apparently closely adhering to each other (Fig. 15). Whether the granules of the protoplasmic mass surrounding the nucleus are regularly arranged in fibrillar rows, cannot be asserted; but it is certain, that from this mass a great number of fine short fibrillæ arise, which, to some extent, anastomose with each other. From these anastomoses a considerable number of long delicate fibrillæ arise, by the junction of which a large process is formed. The anastomosing filaments themselves extend to neighboring ganglionic bodies, stablishing a mutual communication of a number of these bodies, forming a group. The large processes arising from these ganglionic bodies join to form the large nervous trunks which leave the ganglion.

The arrangement of the nervous elements in the insect, resembles in type, as we see, that in the nervous system of the Amphiuma, above described. In both instances, the communication existing between the individual ganglionic bodies is more direct and extensive than in animals of a higher order. In accordance with this arrangement the impression made by peripheral stimuli upon these centres, as well as the nervous energy emanating from them, must be more diffused; the supply of energy to the various organs of these animals, therefore, cannot be as nicely distributed as in animals of a higher organization, in which the nervous elements are differentiated from each other to a greater extent.

The conclusions which may be, finally, drawn from the facts presented in the preceding pages are, that all ganglionic bodies or ganglionic cells, are composed of two elements, anatomically and functionally distinct from each other. The one which is represented by fine nervous fibrillæ, undoubtedly serves to conduct nervous energy, liberated by stimuli applied at the peripheral surface, or emanating from a centre. The function of the other element, represented by a vesicle of a complex nature, the nucleus, is more difficult to determine; but is probably related to the liberation of potential energy residing in it. In supposing that the energy liberated by a stimulus upon the sentient surface may be, without passing through a nerve centre, directly transmitted through the nervous fibrillæ to a muscle or a gland, it might be expected that a contraction of the muscle or a flow of secretion from the gland was to take place, provided the stimulus were sufficiently intense for the purpose. And though such an occurrence may appear improbable, it is not proved that in some instances nervous action may not take place in this manner; for, as we have seen, a number of fibrillæ arriving from the ganglionic cell through one process, leave by way of another neighboring one, without having ever approached the nucleus occupying the centre of the whole. The greater portion of the fibrillæ passes, nevertheless, close to the nucleus, or even comes into actual contact with it. The inference, now, which may be drawn from the relative positions of the fibrillæ and nucleus, is that the nervous stimulus, traveling along the former, becomes increased in strength by an additional amount of liberated potential energy, residing in the latter. This hypothesis is not altogether bare of foundation, when the complex constitution of the nucleus is taken into account. The interior of the nucleus is, besides containing the nucleolus, closely packed with minute granules, and the nucleolus, also of a vesicular nature, is not only similarly filled with granules, but moreover contains one or two bodies of an ambiguous nature, which manifest by their unusual reddish lustre, a considerable power of refraction. The presence of these bodies in the interior of a nucleolus, without regard to their nature, is very unusual; so much the more as one of them contains, even, a dark granule in its centre. Thus, passing from the outer surface of the nucleus toward its centre, we successively meet, in the first place, with the membrane of the nucleus and the granules in its interior; next, with the membrane and granules of the nucleolus; then, with the vesicles or vacuoles in the interior of the latter, and, lastly, with the dark granule in the centre of one of the vacuoles. It seems obvious that nature should have assigned a particular function to a body of a constitution as complicated as that of the so-called "nucleus of the ganglion cell;" and I cannot forbear to point again to the fact, that if any part of the ganglionic body, or ganglionic cell, deserves the name of a nervous cell at all, it is the nucleus; for it alone represents an organic cell in the true sense of the word. Though we know nothing of the material interchanges going on between the different morphological constituents of this cell, we may well presume that its function is related to the secretion, or in other words, generation of nervous energy. This energy may, in its potential form, remain stored up within its particular organism, the nervous cell, to be liberated by the nervous stimuli passing along the nervous fibrillæ surrounding it. Thus, the ganglionic bodies must be looked upon as minute depots of nervous energy, destined to impart to the passing nervous current a greater intensity, by an additional amount of potential energy, which their nuclei, or true nerve cells, contain, and which is liberated by the stimuli passing along the nervous fibrillæ. The whole phenomenon may be compared with that of electric induction.

There can be no doubt but that the office of the nuclei of all tissues is an important one. I, for my part, have always regarded these bodies as the direct descendants of the cells, resulting from the segmentation of the egg, and, as the special organs through which the characters and peculiarities of the parent are transmitted to the offspring; and, therefore, I also presume, that the differentiation of the tissues during the earlier periods of embryonic life, and the preservation of their particular form and character in extra-uterine life, depends upon the influence exerted upon them by the special nuclei each tissue contains. That the integrity of the tissue depends upon the integrity of its nuclei, is a pathological fact. To corroborate this view, I need only refer to the degeneration of the minute blood-vessels, commencing in pathological changes of their nuclei, as an example. And it is for this reason that I venture to direct the attention of neurologists to the condition of the nuclei of the ganglionic bodies in diseased nervous tissues, constantly met with in organic diseases of the nervous system.

As may be presumed from what I have said above, I consider the ganglionic body as an organ destined for the generation and distribution of nervous energy; but incapable of receiving sentient or conscious impressions. It is obvious that impressions can only result in consciousness in those nervous elements which represent the terminus of the nervous apparatus, as well as its commencement in the cortical layer of the brain. Though a large number of ganglionic bodies is distributed throughout this layer, they cannot be looked upon as elements, capable of receiving the manifold sentient impressions coming from the periphery, unless the nucleus is regarded as the particular receiving organ. Such a supposition, however, is not logical for the reason that the nervous fibrillæ, carrying the stimulus to the centres, do not terminate in the nucleus, as has once been asserted by some histologists, but, on the contrary, pass it without entering into any anatomical communication with it, and, finally, terminate in a delicate net-work consisting of minute meshes, formed by minute granulous fibrillæ, and extending throughout the whole cortical layer. The interspaces left by the meshes are filled up by a substance consisting of minute granules, similar in character, or even perhaps identical with those granules of which the delicate net-work is formed. Looking now upon the subject in the true light, it will appear more probable that the stimulus coming from the sentient surface of the periphery, after being increased in strength by an additional amount of liberated potential energy from the true nervous cell, viz.: the nucleus of the ganglion cell, passes along the nervous fibrillæ surrounding this body, without interruption, and, finally, arrives in the terminal nervous net-work, to be, in proportion to its strength or intensity, diffused throughout its delicate meshes. But, as the granules of which the fibrillæ forming the meshes of the net-work are composed, are very probably identical with those representing the substance filling up the meshes of the net-work, it may be also presumed that the stimulus does not remain confined to the fibrillæ of the net-work, but, moreover, extends to the granular substance itself. Thus, the delicate fibrillous net-work, together with the granular substance filling up its meshes, both forming the greater portion of the cortical layer of the brain, would represent the special element, capable of transforming impressions, received from the sentient periphery, into consciousness.

In support of this view, I will mention only one of the many facts which may be adduced in proof of the fallibility of the theory, which locates consciousness in the ganglionic cells of the cortical layer. In admitting as a fact, that the image of external objects is received upon the retina in the same manner as upon the glass plate in the camera of the photographer, it is, in order that this retinal image may be perceived by the mind, absolutely necessary that the impressions upon the retina by each of the countless rays of light, of which this image, in its various colors and shades, is composed, should be carried and imprinted upon the nervous substance of the cortical layer. And, moreover, the mutual arrangement of the impressions thus made upon the cortical layer, and resulting in the perception of the image by the mind, should exactly correspond to the mutual arrangement of the rays of light emanating from the original object. Such an exact arrangement of the impressions upon the cortical layer, however, could not be obtained, if the ganglionic bodies of this layer were the only receiving organs of peripheral stimuli, because the mutual arrangement of these bodies themselves is very irregular. It is true that they are, to a certain extent, arranged into different strata, and that they differ comparatively in size and form in each stratum. Notwithstanding the size, form and mutual arrangement, even in each individual stratum, is too irregular to receive the impressions made by the mathematically arranged rays of light upon the mathematically arranged peripheral elements of the retina, and transmitted through the fibres of the optic nerves to the cortical layer. If we, on the other hand, regard the granular substance of this layer as the receiving organ, the whole process is easily explained, for the number of granules of this substance is so great, and their arrangements so close and regular, as to offer to the stimuli of light a suitable substance of sufficient extent to receive the individual impressions of all the rays, transmitted by each individual nervous fibrilla. In this manner alone, it appears possible that the cerebral image of the object may be a true copy of the retinal image, produced by the stimulus of the rays of light, emanating directly from the object.

The analogous arrangement of the anatomical parts of other systems in the organism, also corroborate this view. If we look, for instance, at the circulatory apparatus of the blood, we find that the arteries and veins are but simple organs of conduction, in which the blood undergoes no perceptible change, as the material interchanges between this fluid and the tissues are taking place while it passes through the capillaries, a system of minute vessels arranged in the form of a net-work. The continuous current of the blood in the arteries, when arriving at the capillary net-work, is broken, its force becoming distributed and diffused throughout the capillary channels in a slower manner; and, the pressure exerted upon the blood being extended in more than one direction, affords an opportunity to this fluid to carry on its material interchanges through the delicate walls of the capillaries with the surrounding tissues.

In an analogous manner, the nervous current, passing along the fibrillæ of the axis cylinders and ganglionic bodies, becomes diffused throughout the terminal net-work of the cortical layer, and leaves its impressions upon the granular substance to which it is communicated.

In the grey matter of the spinal marrow, medulla oblongata, pons varolii and the cerebral ganglia, we also meet with the granular substance, filling up the interspaces left, though not to so large an extent as in the cortical layer of the brain. But, as the meshes of the anastomoses probably formed by the finest ramifications of the processes of the ganglionic bodies must be quite large, the nervous stimulus is not as minutely and regularly diffused throughout, as well as communicated to the granular substance; and, in consequence, the impressions made upon this substance cannot be as distinctly defined, as in the cortical layer of the brain. Judging, however, from the arrangement of the terminal elements in the grey matter of the spinal marrow, medulla oblongata and other nerve centres, being analogous to that of those elements in the cortical layer of the brain, it seems reasonable to suppose that these parts, also, should be the seat of a limited amount of consciousness, which, though insufficient for intellectual manifestations, may nevertheless suffice to give rise to those well known reflex and automatic actions.

EXPLANATION OF THE ILLUSTRATIONS.

Fig. 1.—Ganglionic body of the spinal marrow of the calf, showing its structure of granulous fibrillæ. Magnified 420 diameters.

Fig. 2.—Ganglionic body of the same locality, isolated by Gerlach's method. Magnified 275 diameters.

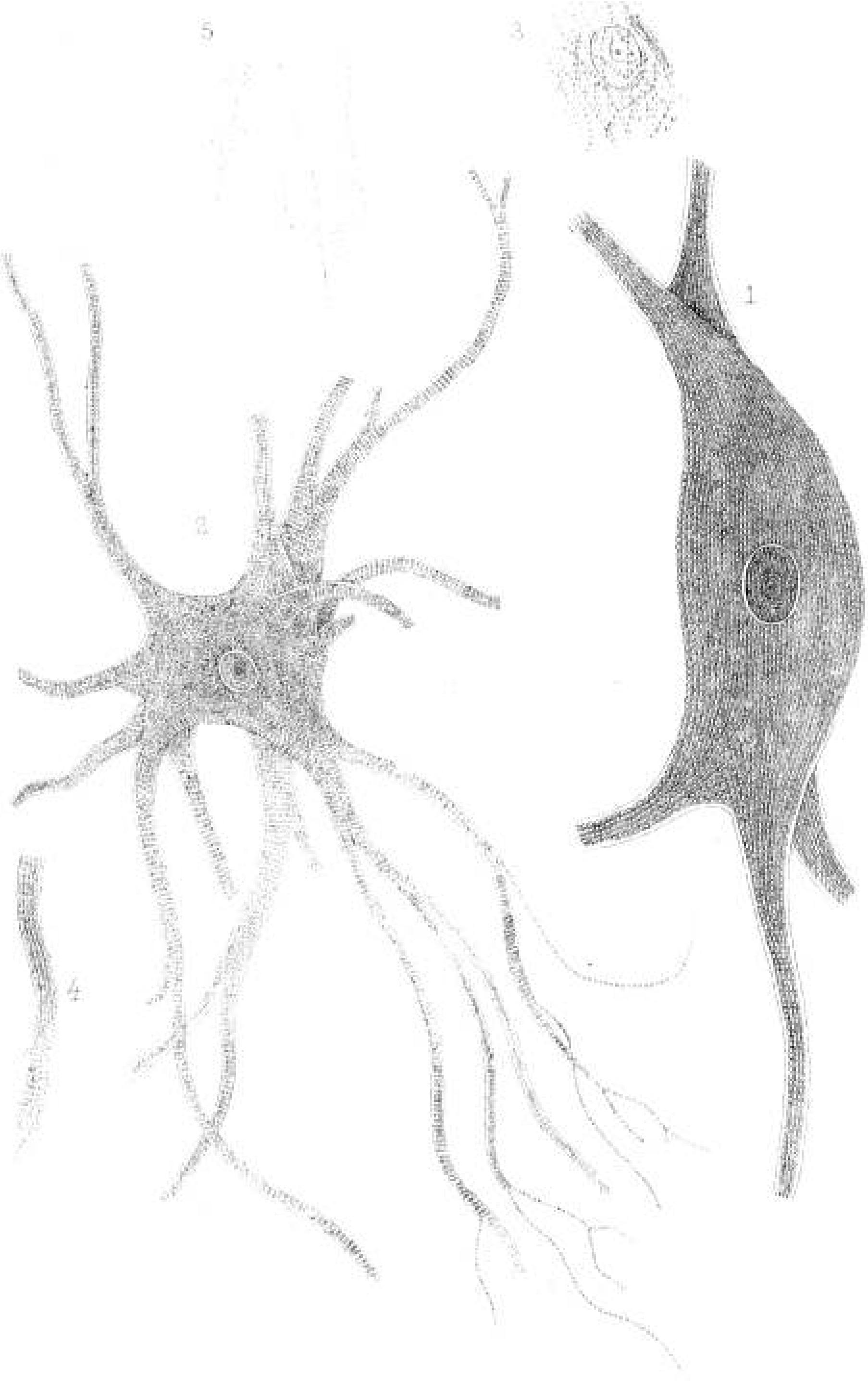
Fig. 3.—Section of a ganglionic body, showing the internal arrangement of its fibrillæ. Magnified 420 diameters.

Fig. 4.—Fragment of a process of a ganglionic body, with a portion of its sheath removed, and showing its fibrillæ isolated. Magnified 420 diameters.

Fig. 5.—Anastomosis of filaments. Magnified 420 diameters.

Figs. 6 to 12.—Ganglionic bodies of the spinal marrow of *Amphiuma tridactylum* (Fig. 6, *a*, free nucleus). Magnified 420 diameters.

Fig. 13.—Transverse section of spinal marrow of the same animal. Magnified 50 diameters.


5
3
1
2
4

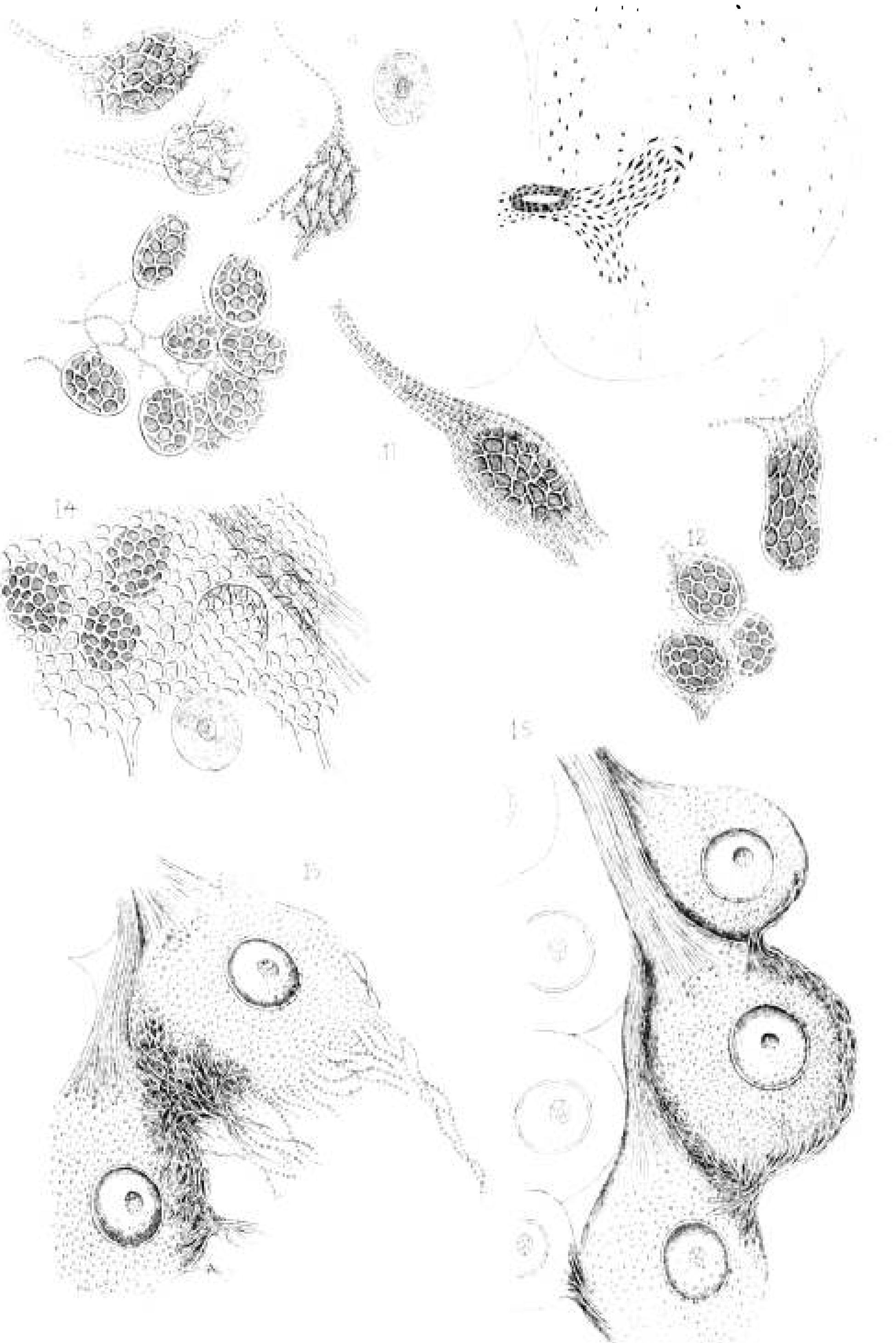

14
11
12
15

Fig. 14.—Ganglionic bodies with their net-work from the cerebrum of Amphiuma tridactylum. Magnified 420 diameters.

Fig. 15.—Ganglionic bodies from one of the abdominal ganglia of *Blatta orientalis* (cockroach), showing their mutual connection by means of anastomosing nervous filaments.

Fig. 16.—The same, after the action of acetic acid.

ART. II.—CONTRIBUTIONS TO ENCEPHALIC ANATOMY.

BY EDWARD C. SPITZKA, M. D., OF NEW YORK.

PART V.

The Organology of the Island of Reil.

IN previous pages of this series I have adverted to the fact that an anatomical identity or similarity existing between the corresponding areas of two given brains, does not imply that those areas are also functionally homologous. The less likely is an anatomical similarity to involve a physiological similarity, the nearer we approach the highest centres; while an atrophy (I am speaking of the *normal* atrophies in the zoological series) or over-development of the central tubular grey matter and the nerve roots, can be readily referred to corresponding defects or higher developments of the related periphery, and comparative physiological deductions can be derived from this relation; the cerebral and cerebellar cortical areas do not admit of such being made. I consider the establishment of this fact so important in its bearing on the question of cerebral localizations, and especially on those which are grounded on localized irritations of the cortex in the lower animals, that I have made an extensive series of dissections of that cortical territory which can be most readily identified in the amniote animals, namely, the island of Reil, in order to illustrate the principle involved.

Various views have been advanced by morphologists and embryologists as to the cause of the cortical retraction, which results in the more or less complete isolation of the island.